

Non-GUT Baryogenesis and Large Scale Structure of the Universe

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Abstract

We discuss a mechanism for producing baryon density perturbations during inflationary stage and study the evolution of the baryon charge density distribution in the framework of the low temperature baryogenesis scenario. This mechanism may be important for the large scale structure formation of the Universe and particularly, may be essential for understanding the existence of a characteristic scale of $130h^{-1}$ Mpc (comoving size) in the distribution of the visible matter.

The detailed analysis showed that both the observed very large scale of the visible matter distribution in the Universe and the observed baryon asymmetry value could naturally appear as a result of the evolution of a complex scalar field condensate, formed at the inflationary stage.

Moreover, according to our model, the visible part of the Universe at present may consist of baryonic and antibaryonic regions, sufficiently separated, so that annihilation radiation is not observed.

keywords: cosmology – large-scale structure - baryogenesis

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1 Introduction

The large scale texture of the Universe shows a great complexity and variety of observed structures, it shows a strange pattern of filaments, voids and sheets. Moreover, due to the increasing amount of different types of observational data and theoretical analysis the last years, it was realized, that there exists a characteristic very large scale of about $130h^{-1}$ Mpc in the large scale texture of the Universe. Namely, the galaxy deep pencil beam surveys (Broadhurst et al. 1988, 1990) found an intriguing periodicity in the very large scale distribution of the luminous matter. The data consisted of several hundred redshifts of galaxies, coming from four distinct surveys, in two narrow cylindrical volumes into the directions of the North and the South Galactic poles of our Galaxy, up to redshifts of more than $z \sim 0.3$, combined to produce a well sampled distribution of galaxies by redshift on a linear scale extending to $2000h^{-1}$ Mpc. The plot of the numbers of galaxies as a function of redshifts displays a remarkably regular redshift distribution, with most galaxies lying in discrete peaks, with a periodicity over a scale of about $130h^{-1}$ Mpc comoving size.

It was realized also that the density peaks in the regular space distribution of galaxies in the redshift survey of Broadhurst et al. (1990), correspond to the location of superclusters, as defined by rich clusters of galaxies in the given direction (Bahcall 1991). The survey of samples in other directions, located near the South Galactic pole also gave indications for a regular distribution on slightly different scales near $100h^{-1}$ Mpc (Ettori et al. 1995, see also Tully et al. 1992 and Guzzo et al. 1992, Willmer et al. 1994). This discovery of a large scale pattern at the galactic poles was confirmed in a wider angle survey of 21 new pencil beams distributed over 10 degree field at both galactic caps (Broadhurst et al. 1995) and also by the new pencil-beam galaxy redshift data around the South Galactic pole region (Ettori et al. 1997).

The analysis of other types of observations confirm the existence of this periodicity. Namely, such structure is consistent with the reported periodicity in the distribution of quasars and radio galaxies (Foltz et al. 1989, Komberg et al. 1996, Quashnock et al. 1996, Petitjeau 1996, Cristiani 1998) and Lyman- α forest (Chu & Zhu 1989); the studies on spatial distribution of galaxies (both optical and IRAS) and clusters of galaxies (Kopylov et al. 1984, de Lapparent et al. 1986, Geller & Huchra 1989, Huchra et al. 1990, Bertshinger et al. 1990, Rowan-Robinson et al. 1990, Buryak et al. 1994, Bahcall 1992, Fetisova et al. 1993a, Einasto et al. 1994, Cohen et al. 1996, Bellanger & de Lapparent 1995) as well as peculiar velocity information (Lynden-Bell et al. 1988, Lauer & Postman 1994, Hudson et al. 1999) suggest the existence of a large scale superclusters-voids network with a characteristic scale around $130h^{-1}$ Mpc.

An indication of the presence of this characteristic scale in the distribution of clusters has been found also from the studies of the correlation functions and power spectrum of clusters of galaxies (Kopylov et al. 1988, Bahcall 1991, Mo et al. 1992, Peacock & West 1992, Deckel et al. 1992, Saar et al. 1995, Einasto et al. 1993, Einasto & Gramann 1993, Fetisova et al. 1993b, Frisch et al. 1995, Einasto et al. 1997b, Retzlaff et al. 1998, Tadros et al. 1997). The galaxy correlation function of the Las Campanas redshift survey also showed the presence of a secondary maximum at the same scale and a strong peak in the 2-dimensional power spectrum corresponding to an excess power at about 100 Mpc (Landy et al. 1995, 1996, Shectman et al. 1996, Doroshkevich et al. 1996, Geller et al. 1997, Tucker et al. 1999). The supercluster distribution was shown also to be not random but rather described as some weakly correlated network of superclusters and voids with typical mean separation of $100 - 150h^{-1}$ Mpc. Many known superclusters were identified with the vertices of an octahedron superstructure network (Battaner 1998). The network was proven to resemble a cubical lattice, with a periodic distribution of the rich clusters along the main

axis (coinciding with the supergalactic Y axis) of the network, with a step $\sim 130h^{-1}$ Mpc (Toomet et al. 1999). These results are consistent with the statistical analysis of the pencil beam surveys data (Kurki-Suonio et al. 1990, Amendola 1994), which advocates a regular structure.

Recently performed study of the whole-sky distribution of high density regions defined by very rich Abell and APM clusters of galaxies (Baugh 1996, Einasto et al. 1994, 1996, 1997a, Gaztanaga & Baugh 1997, Landy et al. 1996, Retzlaff et al. 1998, Tadros et al. 1997, Kerscher 1998) confirmed from 3-dimensional data the presence of the characteristic scale of about $130h^{-1}$ Mpc of the spatial inhomogeneity of the Universe, found by Broadhurst et al. (1988, 1990) from the one dimensional study. The combined evidence from cluster and CMB data (Baker et al. 1999, Scott et al. 1996) also favours the presence of a peak at $130h^{-1}$ Mpc and a subsequent break in the initial power spectrum (Atrio-Barandela et al. 1997, Broadhurst&Jaffe 1999). For a recent review of the regularity of the Universe on large scales see Einasto (1997).

Concerning all these rather convenient data, pointing that different objects trace the same structure at large scales, we are forced to believe in the real existence of the $130h^{-1}$ Mpc as a typical scale for the matter distribution in the Universe (see also Einasto et al 1998). However, this periodicity points to the existence of a significantly larger scale in the observed today Universe structure than predicted by standard models of structure formation by gravitational instability (Davis 1990, Szalay et al. 1991, Davis et al. 1992, Luo & Vishniac 1993, Bahcall 1994, Retzlaff et al. 1998, Atrio-Barandela et al. 1997, Lesgourgues et al. 1998, Meiksin et al. 1998, Eisenstein et al. 1998, Eisenstein & Hu 1997a, 1997b) and is rather to be regarded as a new feature appearing only when very large scales ($> 100h^{-1}$ Mpc) are probed.

The problem of the generation of the spatial periodicity in the density distribution of luminous matter at large scales was discussed in numerous publications (Lumsden et al. 1989, Ostriker & Strassler 1989, Davis 1990, Coles 1990, Kurki-Suonio et al. 1990, Trimble 1990, Kofman et al. 1990, Ikeuchi & Turner 1991, van de Weygaert 1991, Buchert & Mo 1991, SubbaRao & Szalay 1992, Coleman & Pietronero 1992, Hill et al. 1989, Tully et al. 1992, Chincarini 1992, Weis & Buchert 1993, Atrio-Barandela et al. 1997, Lesgourgues et al. 1998, Eisenstein & Hu 1997a, Meiksin et al. 1998, Eisenstein et al. 1998, etc.). It was shown that a random structure could not explain the observed distribution. Statistical analysis of the deviations from periodicity showed that even for a perfectly regular structure a somewhat favoured direction and/or location within the structure may be required. The presence of the observed periodicity up to a great distance and in different directions seems rather amazing. Having in mind this results and the difficulties that perturbative models encounter in explaining the very large scale structure formation (namely the existence of the very large characteristic scale and the periodicity of the visible matter distribution), we chose another way of exploration, namely, we assume these as a typical new feature characteristic only for very large scales ($> 100h^{-1}$ Mpc). I. e. we consider the possibility that density fluctuations required to explain the present cosmological largest scale structures of the universal texture may have arisen in a different from the standard way, they may be a result from a completely different mechanism not necessarily with gravitational origin.

Such a successful mechanism was already proposed (Chizhov & Dolgov 1992) and analyzed in the framework of high-temperature baryogenesis scenarios.³ According to the discussed mechanism an additional complex scalar field (besides inflaton) is assumed to

³By high-temperature baryogenesis scenarios we denote here those scenarios which proceed at very high energies of the order of the Grand Unification scale, and especially the GUT baryogenesis scenarios. In contrast, low temperature baryogenesis scenarios like Affleck and Dine scenario and electroweak baryogenesis, proceed at several orders of magnitude lower energies.

be present at the inflationary epoch, and it yields the extra power at the very large scale discussed. Primordial baryonic fluctuations are produced during the inflationary period, due to the specific evolution of the space distribution of the complex scalar field, carrying the baryon charge.

In the present work we study the possibility of generating of periodic space distribution of primordial baryon density fluctuations at the end of inflationary stage, applying this mechanism for the case of low temperature baryogenesis with baryon charge condensate of Dolgov & Kirilova (1991). The preliminary analysis of this problem, provided in Chizhov & Kirilova (1994), proved its usefulness in that case. Here we provide detail analysis of the evolution of the baryon density perturbations from the inflationary epoch till the baryogenesis epoch and describe the evolution of the spatial distribution of the baryon density. The production of matter-antimatter asymmetry in this scenario proceeds generally at low energies ($\leq 10^9$ GeV). This is of special importance having in mind that the low-temperature baryogenesis scenarios are the preferred ones, as far as for their realization in the postinflationary stage it is not necessary to provide considerable reheating temperature typical for GUT high temperature baryogenesis scenarios. Hence, the discussed model (Dolgov & Kirilova 1991) has several attractive features: (a) It is compatible with the inflationary models as far as it does not suffer from the problem of insufficient reheating. (b) Generally, this scenario evades the problem of washing out the previously produced baryon asymmetry at the electroweak transition. (c) And as it will be proved in the following it may solve the problem of large scale periodicity of the visible matter.

It was already discussed in (Dolgov 1992, Chizhov & Dolgov 1992) a periodic in space baryonic density distribution can be obtained provided that the following assumptions are realized:

- (a) There exists a complex scalar field ϕ with a mass small in comparison with the Hubble parameter during inflation.
- (b) Its potential contains nonharmonic terms.
- (c) A condensate of ϕ forms during the inflationary stage and it is a slowly varying function of space points.

All these requirements can be naturally fulfilled in our scenario of the scalar field condensate baryogenesis (Dolgov & Kirilova 1991) and in low temperature baryogenesis scenarios based on the Affleck and Dine mechanism (Affleck & Dine 1985).

In case when the potential of ϕ is not strictly harmonic the oscillation period depends on the amplitude $P(\phi_0(r))$, and it on its turn depends on r . Therefore, a monotonic initial space distribution will soon result into spatial oscillations of ϕ (Chizhov & Dolgov 1992). Correspondingly, the baryon charge, contained in ϕ : $N_B = i\phi^* \overleftrightarrow{\partial}_0 \phi$, will have quasi-periodic behavior. During Universe expansion the characteristic scale of the variation of N_B will be inflated up to a cosmologically interesting size. Then, if ϕ has not reached the equilibrium point till the baryogenesis epoch t_B , the baryogenesis would make a snapshot of the space distribution of $\phi(r, t_B)$ and $N_B(r, t_B)$, and thus the present periodic distribution of the visible matter may date from the spatial distribution of the baryon charge contained in the ϕ field at the advent of the B -conservation epoch.

Density fluctuations with a comoving size today of $130h^{-1}$ Mpc reentered the horizon at late times at a redshift of about 10 000 and a mass of $10^{18}M_o$. After recombination the Jeans mass becomes less than the horizon and the fluctuations of this large mass begin to grow. We propose that these baryonic fluctuations, periodically spaced, lead to an enhanced formation of galaxy superclusters at the peaks of baryon overdensity. The concentration of baryons into periodic shells may have catalysed also the clustering of matter coming from the inflaton decays onto these ‘‘baryonic nuclei’’. After baryogenesis

proceeded, superclusters may have formed at the high peaks of the background field (the baryon charge carrying scalar field, we discuss). (See the results of the statistical analysis (Plionis 1995), confirming the idea that clusters formed at the high peaks of background field, which is analogous to our assumption.) We imply that afterwards the self gravity mechanisms might have optimized the arrangement of this structure into the thin regularly spaced dense baryonic shells and voids in between with the characteristic size of $130h^{-1}Mpc$ observed today.

The analysis showed that in the framework of our scenario both the generation of the baryon asymmetry and the periodic distribution of the baryon density can be explained simultaneously as due to the evolution of a complex scalar field.

Moreover, for a certain range of parameters the model predicts that the Universe may consist of sufficiently separated baryonic and antibaryonic shells. This possibility was discussed in more detail elsewhere (Kirilova 1998). This is an interesting possibility as far as the observational data of antiparticles in cosmic rays and the gamma rays data do not rule out the possibility for existence of superclusters of galaxies of antimatter in the Universe (Steigman 1976, Ahlen et al. 1982, 1988, Stecker 1985, 1989, Gao et al. 1990). The observations exclude the possibility of noticeable amount of antimatter in our Galaxy, however, they are not sensitive enough to test the existence of antimatter extragalactic regions. I.e. current experiments (Salamon et al. 1990, Ahlen et al. 1994, Golden et al. 1994, 1996, Yoshimura et al. 1995, Mitchell et al. 1996, Barbiellini & Zalateu 1997, Moiseev et al. 1997, Boesio et al. 1997, Orito et al. 1999, etc.) put only a lower limit on the distance to the nearest antimatter-rich region, namely ~ 20 Mpc. Future searches for antimatter among cosmic rays are expected to increase this lower bound by an order of magnitude. Namely, the reach of the AntiMatter Spectrometer is claimed to exceed 150 Mpc (Ahlen et al. 1982) and its sensitivity is three orders of magnitudes better than that of the previous experiments (Battiston 1997, Plyaskin et al. 1998). For a more detail discussion on the problem of existence of noticeable amounts of antimatter at considerable distances see Dolgov (1993), Cohen et al. (1998), Kinney et al. (1997).

The following section describes the baryogenesis model and the last section deals with the generation of the periodicity of the baryon density and discusses the results.

2 Description of the model. Main characteristics.

Our analysis was performed in the framework of the low temperature non-GUT baryogenesis model described in (Dolgov & Kirilova 1991), based on the Affleck and Dine SUSY GUT motivated mechanism for generation of the baryon asymmetry (Affleck & Dine 1985). In this section we describe the main characteristics of the baryogenesis model, which are essential for the investigation of the periodicity in the next section. For more detail please see the original paper.

2.1 Generation of the baryon condensate.

The essential ingredient of the model is a squark condensate ϕ with a nonzero baryon charge. It naturally appears in supersymmetric theories and is a scalar superpartner of quarks. The condensate $\langle \phi \rangle \neq 0$ is formed during the inflationary period as a result of the enhancement of quantum fluctuations of the ϕ field (Vilenkin & Ford 1982, Linde 1982, Bunch & Davies 1978, Starobinsky 1982): $\langle \phi^2 \rangle = H^3 t / 4\pi^2$. The baryon charge of the field is not conserved at large values of the field amplitude due to the presence of the B nonconserving self-interaction terms in the field's potential. As a result, a condensate of a

baryon charge (stored in $\langle \phi \rangle$) is developed during inflation with a baryon charge density of the order of H_I^3 , where H_I is the Hubble parameter at the inflationary stage.

2.2 Generation of the baryon asymmetry.

After inflation ϕ starts to oscillate around its equilibrium point with a decreasing amplitude. This decrease is due to the Universe expansion and to the particle production by the oscillating scalar field (Dolgov & Kirilova 1990, 1991). Here we discuss the simple case of particle production when ϕ decays into fermions and there is no parametric resonance. We expect that the case of decays into bosons due to parametric resonance (Kofman et al. 1994, 1996, Shtanov et al. 1995, Boyanovski et al. 1995, Yoshimura 1995, Kaiser 1996), especially in the broad resonance case, will lead to an explosive decay of the condensate, and hence an insufficient baryon asymmetry. Therefore, we explore the more promising case of ϕ decaying into fermions.

In the expanding Universe ϕ satisfies the equation

$$\ddot{\phi} - a^{-2}\partial_i^2\phi + 3H\dot{\phi} + \frac{1}{4}\Gamma\dot{\phi} + U'_\phi = 0, \quad (1)$$

where $a(t)$ is the scale factor and $H = \dot{a}/a$.

The potential $U(\phi)$ is chosen in the form

$$U(\phi) = \frac{\lambda_1}{2}|\phi|^4 + \frac{\lambda_2}{4}(\phi^4 + \phi^{*4}) + \frac{\lambda_3}{4}|\phi|^2(\phi^2 + \phi^{*2}) \quad (2)$$

The mass parameters of the potential are assumed small in comparison to the Hubble constant during inflation $m \ll H_I$. In supersymmetric theories the constants λ_i are of the order of the gauge coupling constant α . A natural value of m is $10^2 \div 10^4$ GeV. The initial values for the field variables can be derived from the natural assumption that the energy density of ϕ at the inflationary stage is of the order H_I^4 , then $\phi_o^{max} \sim H_I \lambda^{-1/4}$ and $\dot{\phi}_o = 0$.

The term $\Gamma\dot{\phi}$ in the equations of motion explicitly accounts for the eventual damping of ϕ as a result of particle creation processes. The explicit account for the effect of particle creation processes in the equations of motion was first provided in (Chizhov & Kirilova 1994, Kirilova & Chizhov 1996). The production rate Γ was calculated in (Dolgov & Kirilova 1990). For simplicity here we have used the perturbation theory approximation for the production rate $\Gamma = \alpha\Omega$, where Ω is the frequency of the scalar field.⁴ For $g < \lambda^{3/4}$, Γ considerably exceeds the rate of the ordinary decay of the field $\Gamma_m = \alpha m$. Fast oscillations of ϕ after inflation result in particle creation due to the coupling of the scalar field to fermions $g\phi\bar{f}_1f_2$, where $g^2/4\pi = \alpha_{SUSY}$. Therefore, the amplitude of ϕ is damped as $\phi \rightarrow \phi \exp(-\Gamma t/4)$ and the baryon charge, contained in the ϕ condensate, is considerably reduced. It was discussed in detail in Dolgov & Kirilova (1991) that for a constant Γ this reduction is exponential and generally, for a natural range of the model's parameters, the baryon asymmetry is waved away till baryogenesis epoch as a result of the particle creation processes. Fortunately, in the case without flat directions of the potential, the production rate is a decreasing function of time, so that the damping process may be slow enough for a considerable range of acceptable model parameters values of m , H , α , and λ , so that the baryon charge contained in ϕ may survive until the advent of the B -conservation epoch. Generally, in cases of more effective particle creation, like in the case with flat directions in the potential, or in the case when ϕ decays spontaneously into bosons due to parametric resonance, the discussed mechanism of the baryon asymmetry generation cannot be successful. Hence, it cannot be useful also for the generation of the matter periodicity.

⁴For the toy model, we discuss here, we consider this approximation instructive enough.

2.3 Baryogenesis epoch t_B .

When inflation is over and ϕ relaxes to its equilibrium state, its coherent oscillations produce an excess of quarks over antiquarks (or vice versa) depending on the initial sign of the baryon charge condensate. This charge, diluted further by some entropy generating processes, dictates the observed baryon asymmetry. This epoch when ϕ decays to quarks with non-zero average baryon charge and thus induces baryon asymmetry we call baryogenesis epoch. The baryogenesis epoch t_B for our model coincides with the advent of the baryon conservation epoch, i.e. the time after which the mass terms in the equations of motion cannot be neglected. In the original version (Affleck & Dine 1985) this epoch corresponds to energies $10^2 - 10^4$ GeV. However, as it was already explained, the amplitude of ϕ may be reduced much more quickly due to the particle creation processes and as a result, depending on the model's parameters the advent of this epoch may be considerably earlier. For the correct estimation of t_B and the value of the generated baryon asymmetry, it is essential to account for the eventual damping of the field's amplitude due to particle production processes by an external time-dependent scalar field, which could lead to a strong reduction of the baryon charge contained in the condensate.

3 Generation of the baryon density periodicity.

In order to explore the spatial distribution behavior of the scalar field and its evolution during Universe expansion it is necessary to analyze eq.(1). We have made the natural assumption that initially ϕ is a slowly varying function of the space coordinates $\phi(r, t)$. The space derivative term can be safely neglected because of the exponential rising of the scale factor $a(t) \sim \exp(H_I t)$. Then the equations of motion for $\phi = x + iy$ read

$$\begin{aligned}\ddot{x} + 3H\dot{x} + \frac{1}{4}\Gamma_x\dot{x} + (\lambda + \lambda_3)x^3 + \lambda'xy^2 &= 0 \\ \ddot{y} + 3H\dot{y} + \frac{1}{4}\Gamma_y\dot{y} + (\lambda - \lambda_3)y^3 + \lambda'yx^2 &= 0\end{aligned}\tag{3}$$

where $\lambda = \lambda_1 + \lambda_2$, $\lambda' = \lambda_1 - 3\lambda_2$.

In case when at the end of inflation the Universe is dominated by a coherent oscillations of the inflaton field $\psi = m_{PL}(3\pi)^{-1/2} \sin(m_\psi t)$, the Hubble parameter is $H = 2/(3t)$. In this case it is convenient to make the substitutions $x = H_I(t_i/t)^{2/3}u(\eta)$, $y = H_I(t_i/t)^{2/3}v(\eta)$ where $\eta = 2(t/t_i)^{1/3}$. The functions $u(\eta)$ and $v(\eta)$ satisfy the equations

$$\begin{aligned}u'' + 0.75 \alpha \Omega_u(u' - 2u\eta^{-1}) + u[(\lambda + \lambda_3)u^2 + \lambda'v^2 - 2\eta^{-2}] &= 0 \\ v'' + 0.75 \alpha \Omega_v(v' - 2v\eta^{-1}) + v[(\lambda - \lambda_3)v^2 + \lambda'u^2 - 2\eta^{-2}] &= 0.\end{aligned}\tag{4}$$

The baryon charge in the comoving volume $V = V_i(t/t_i)^2$ is $B = N_B \cdot V = 2(u'v - v'u)$. The numerical calculations were performed for $u_o, v_o \in [0, \lambda^{-1/4}]$, $u'_o, v'_o \in [0, 2/3\lambda^{-1/4}]$. For simplicity we considered the case: $\lambda_1 > \lambda_2 \sim \lambda_3$, when the unharmonic oscillators u and v are weakly coupled. For each set of parameter values of the model λ_i we have numerically calculated the baryon charge evolution $B(\eta)$ for different initial conditions of the field corresponding to the accepted initial monotonic space distribution of the field (see Figs. 1,2).

The numerical analysis confirmed the important role of particle creation processes for baryogenesis models and large scale structure periodicity (Chizhov & Kirilova 1994, 1996)

which were obtained from an approximate analytical solution. In the present work we have accounted for particle creation processes explicitly.⁵

The space distribution of the baryon charge is calculated for the moment t_B . It is obtained from the evolution analysis $B(\eta)$ for different initial values of the field, corresponding to its initial space distribution $\phi(t_i, r)$ (Fig. 3). As it was expected, in the case of nonharmonic field's potential, the initially monotonic space behavior is quickly replaced by space oscillations of ϕ , because of the dependence of the period on the amplitude, which on its turn is a function of r . As a result in different points different periods are observed and space behavior of ϕ becomes quasiperiodic. Correspondingly, the space distribution of the baryon charge contained in ϕ becomes quasiperiodic as well. Therefore, the space distribution of baryons at the moment of baryogenesis is found to be periodic.

The observed space distribution of the visible matter today is defined by the space distribution of the baryon charge of the field ϕ at the moment of baryogenesis t_B , $B(t_B, r)$. So, that at present the visible part of the Universe consists of baryonic shells, divided by vast underdense regions. *For a wide range of parameters' values the observed average distance of $130h^{-1}$ Mpc between matter shells in the Universe can be obtained. The parameters of the model ensuring the necessary observable size between the matter domains belong to the range of parameters for which the generation of the observed value of the baryon asymmetry may be possible in the model of scalar field condensate baryogenesis.* This is an attractive feature of this model because both the baryogenesis and the large scale structure periodicity of the Universe can be explained simply through the evolution of a single scalar field.

Moreover, for some model's variations the presence of vast antibaryonic regions in the Universe is predicted. This is an interesting possibility as far as the observational data do not rule out the possibility of antimatter superclusters in the Universe. The model proposes an elegant mechanism for achieving a sufficient separation between regions occupied by baryons and those occupied by antibaryons, necessary in order to inhibit the contact of matter and antimatter regions with considerable density.

It is interesting, having in mind the positive results of this investigation, to provide a more precise study of the question for different possibilities of particle creation and their relevance for the discussed scenario of baryogenesis and periodicity generation. In the case of narrow-band resonance decay the final state interactions regulate the decay rate, parametric amplification is effectively suppressed (Allahverdi & Campbell 1997) and does not drastically enhance the decay rate. Therefore, we expect that this case will be interesting to explore. Another interesting case may be the case of strong dissipative processes of the products of the parametric resonance. As far as the dissipation reduces the resonant decay rate (Kolb et al. 1996, Kasuya & Kawasaki 1996) it may be worthwhile to consider such a model as well.

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⁵It was shown, that the damping effect due to the particle creation is proportional to the initial amplitudes of the field. As far as the particle creation rate is proportional to the field's frequency, it can be concluded that the frequency depends on the initial amplitudes. This result confirms our analytical estimation provided in earlier works.

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Captions

Figure 1: The evolution of the baryon charge $B(\eta)$ contained in the condensate $\langle \phi \rangle$ for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = \alpha = 10^{-3}$, $H_I/m = 10^7$, $\phi_o = H_I \lambda^{-1/4}$, and $\dot{\phi}_o = 0$.

Figure 2: The evolution of the baryon charge $B(\eta)$ contained in the condensate $\langle \phi \rangle$ for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = \alpha = 10^{-3}$, $H_I/m = 10^7$, $\phi_o = \frac{1}{50} H_I \lambda^{-1/4}$, and $\dot{\phi}_o = 0$.

Figure 3: The space distribution of baryon charge at the moment of baryogenesis for $\lambda_1 = 5 \times 10^{-2}$, $\lambda_2 = \lambda_3 = \alpha = 10^{-3}$, $H_I/m = 10^7$.

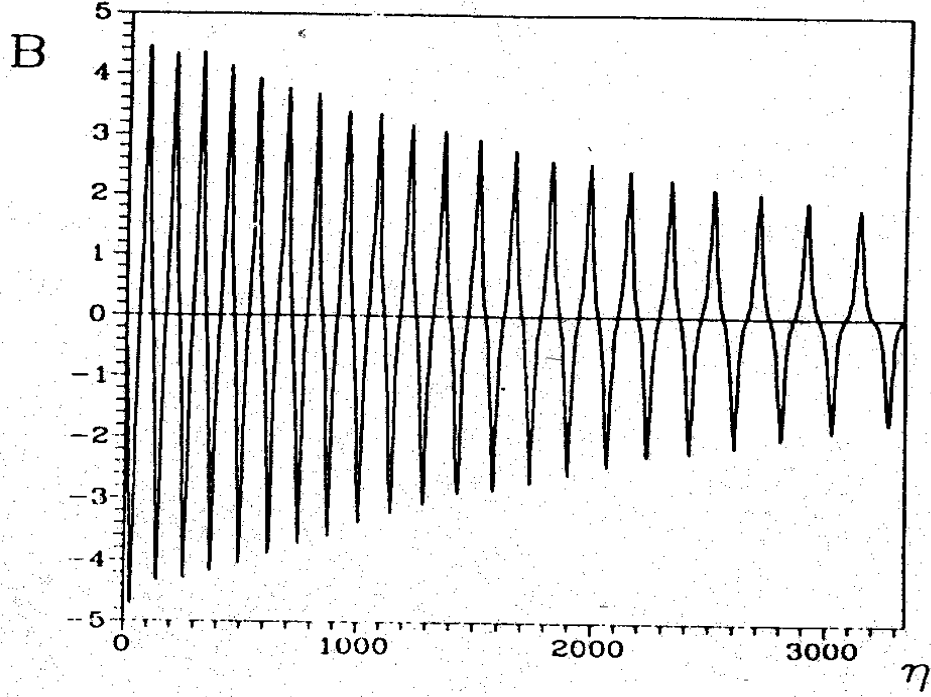


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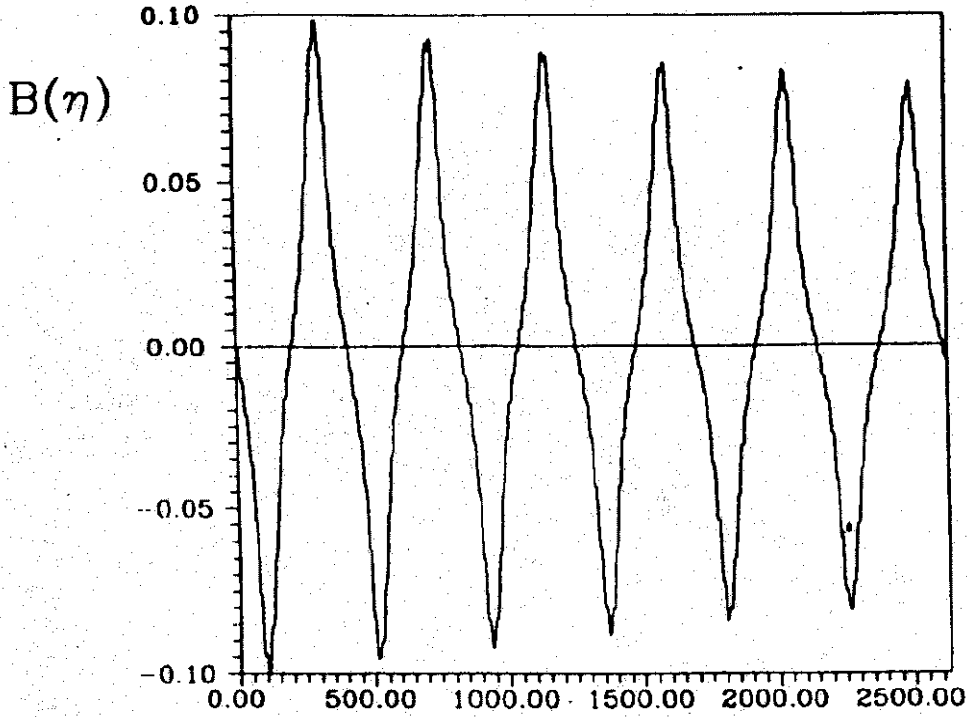


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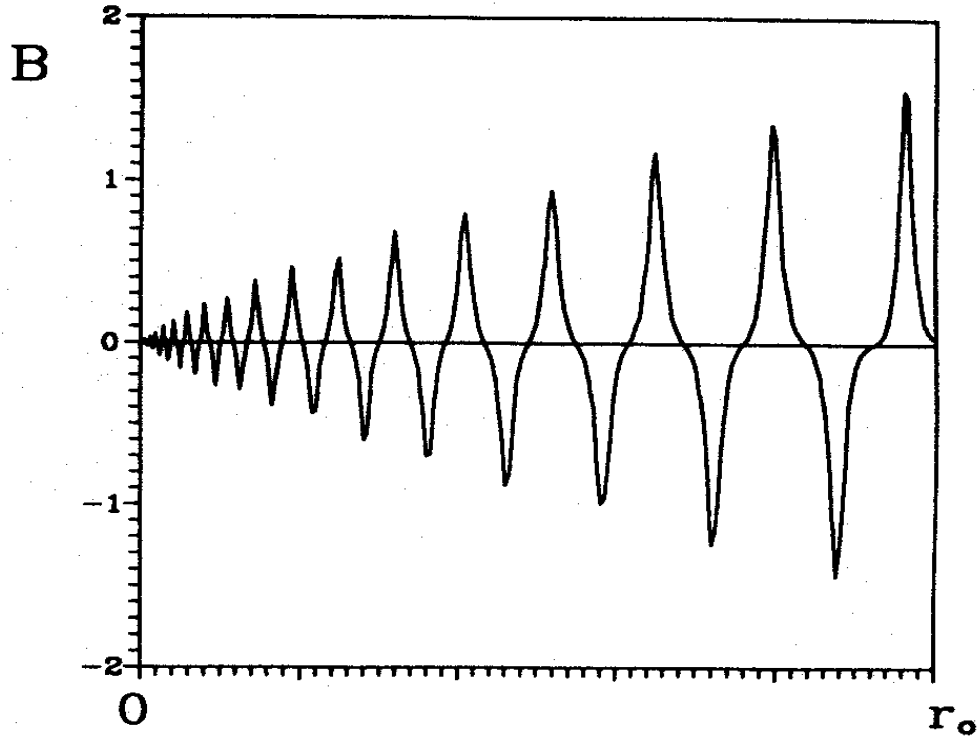


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